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CP measurement of the Higgs-tau coupling

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The Standard Model predicts that the Higgs boson is even under charge-parity inversion. In this report, we explain the result of the first direct measurement of the CP structure of the Yukawa coupling between the Higgs boson and tau leptons. The analysis is based on a data set from proton-proton collision corresponding to an integrated luminosity of 137 fb^{-1}, recorded by the CMS experiment at the Large Hadron Collider. The result is consistent with the Standard Model prediction and excludes a pure CP-odd coupling by 3.2σ.

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The Standard Model (SM) predicts the charge-parity (CP) of the Higgs boson to be even. Therefore, any deviation from a pure CP-even Higgs coupling is a clear indication of beyond the SM physics. In particular, the coupling of the Higgs boson to fermions is of great interest as it provides easier access to measure small components of CP-odd couplings [1]. Among fermions with sizable coupling to the Higgs boson, taus provide a comparatively clean signal.

The Lagrangian describing the $H \to \tau^+\tau^-$ interaction can be parametrized as [2]:

$$L_Y = -g_\tau(\cos(\phi_{\tau\tau})\bar{\tau}\tau + \sin(\phi_{\tau\tau})\bar{\tau}i\gamma_5\tau)H \tag{1}$$

in which g_τ is the effective Yukawa interaction strength and $\phi_{\tau\tau}$ is CP mixing angle which would be $0°(90°)$ for a pure CP-even (CP-odd) coupling and takes other values for mixed CP scenarios. $\phi_{\tau\tau}$ can be measured through an observable, ϕ_{CP}, which is defined using the angle between the planes spanned by the decay of the τ^+ and τ^- [3]. It can be shown [2] that:

$$d\Gamma(H \to \tau^+\tau^-) \propto \cos(\phi_{CP} - 2\phi_{\tau\tau}) \tag{2}$$

Fig. 1 shows a simulation of the ϕ_{CP} distribution for the CP-even, CP-odd and maximally-mixed couplings, as well as the Z boson decay. In this example, each τ decays to one charged pion and a neutrino. The ϕ_{CP} distribution of a mixed CP coupling is shifted by $2\phi_{\tau\tau}$ from the distribution of the CP-even coupling, as also visible from Eq. 2.

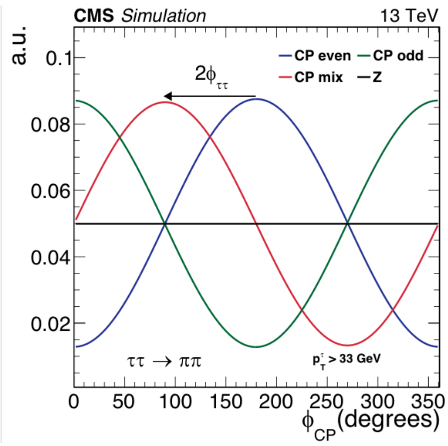

Figure 1: The normalized ϕ_{CP} distribution of a pure CP-even (blue), pure CP-odd (green) and a maximally-mixed (red) Higgs coupling. The Z-boson yields a flat distribution (black) and is part of the background in this study. In this simulation, each τ decays to a charged pion and a neutrino.

This analysis is performed with a data set of proton-proton collision corresponding to 137 fb^{-1} integrated luminosity which are recorded in the CMS detector at the LHC during 2016, 2017 and 2018. The $\tau_h\tau_h$ and $\tau_h\tau_\mu$ final states are targeted, in which τ_h and τ_μ represent the decay of the τ to hadrons and a muon, respectively.

There are two main methods for reconstructing ϕ_{CP}: The *impact parameter* and *neutral pion* method. The former is primarily used when a τ decays to one particle (excluding neutrinos), such as $\tau^- \to \pi^-\nu_\tau$, and the latter is used for the rest of the decays. These methods are explained in [4].

In order to get maximum CP sensitivity while retaining enough statistics, several optimization techniques are employed. Machine learning (ML) classifiers are developed to distinguish signal

(Higgs) from background. A separate ML classifier is trained [5] to distinguish different τ_h decays which is essential as they have different CP sensitivity. More optimizations are explained in Sec. 5 of [3].

Finally, the observed (expected) value of $\phi_{\tau\tau}$ is found to be $4 \pm 17°$ ($0 \pm 23°$). Fig. 2 shows the negative log-likelihood scan of $\phi_{\tau\tau}$. This result is consistent with the SM predictions within uncertainties and excludes a pure CP-odd scenario by 3.2 standard deviations.

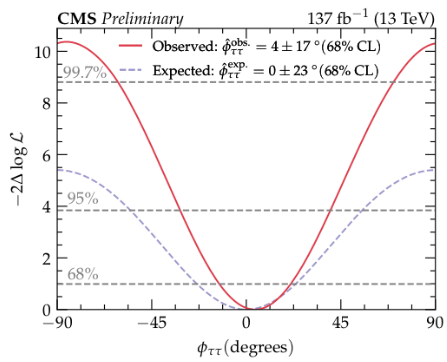

Figure 2: Negative log-likelihood scan of $\phi_{\tau\tau}$ for the combined analysis of $\tau_h\tau_h$ and $\tau_h\tau_\mu$ final states.

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